PROGRESS REPORT

PR 91565-430-8

For the Period of February 15, 1963 - March 15, 1963

DEVELOPMENT OF AUXILIARY ELECTRIC
POWER SUPPLY SYSTEM

NASA Contract NAS 3-2550

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INTRODUCTION

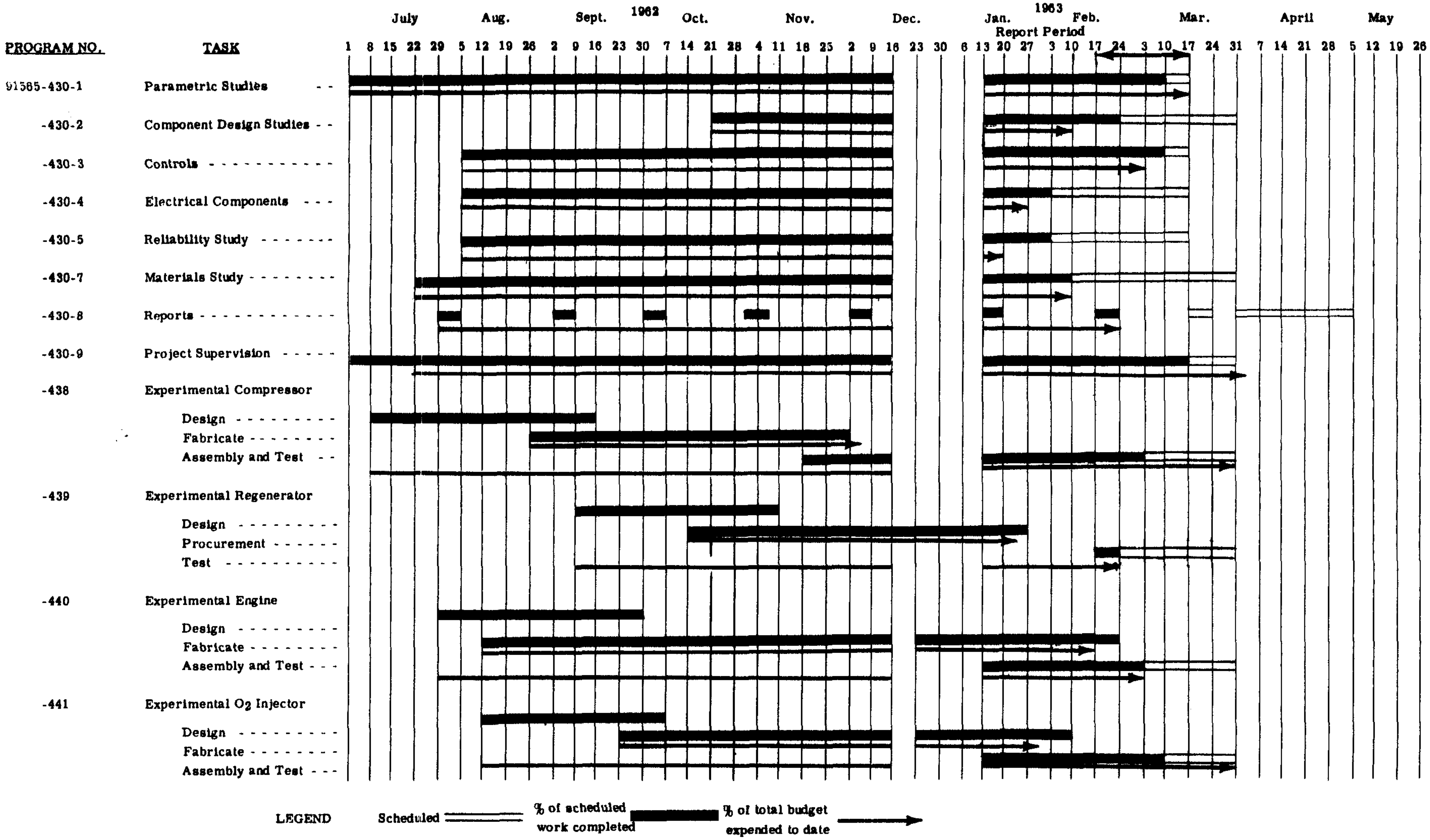
This report describes the work accomplished on the program conducted by Vickers Incorporated under NASA Contract NAS 3-2550 from February 15, 1963 to March 15, 1963. The objectives of this program are to conduct an engineering study culminating in the design of an electrical power generation system operating on hydrogen and oxygen in a space environment, and to conduct preliminary testing on critical system components.

PROGRAM SCHEDULE

The program schedule is shown in Fig. 1. The schedule has been extended to take advantage of a 30 day extension which was agreed to by NASA and Vickers personnel January 17, 1963. It is expected that completion of the program can be accomplished in accordance with the revised schedule shown in Fig. 1.

Fig. 1

PROGRAM SCHEDULE NASA CONTRACT NAS 3-2550



PARAMETRIC STUDIES

No effort has been expended on parametric studies during this time period. The final report section on parametric studies will be completed by April 30, 1963.

COMPONENT DESIGN STUDIES

Design layout work has been started and design analysis is continuing in the following areas of component design studies:

Balancing and Vibration Isolation

The Lord Manufacturing Company was consulted with regard to engine mounts. They recommended a very soft elastomer multiplane mount with center of gravity installation. Maximum deflection will be limited by a snubbing action rather than by stiff mounts. In this case, power system vibration will be isolated effectively under steady state conditions without attempting to remove all transient shocks due to take-off, maneuvers, etc. The entire power system will be rigidly connected and mounted as a unit to take advantage of the weight of the electrical components.

The engine reciprocating weight will be balanced by a dummy weight pivoting about a lever arm and driven by an eccentric on the crankshaft. This eccentric has a stroke of one-half the engine stroke, with a balance weight of double the piston assembly weight. The eccentric is mounted on one crank cheek and the rotating weight is counterbalanced equally on both crank cheeks. This arrangement provides for complete balancing except for a small rocking couple caused by the dummy weight and the power piston operating along slightly different centerlines.

Compressors

There is a single stage hydrogen compressor exhausting at 300 psi and a two stage oxygen compressor attaining 1000 psi. Both compressors are similar in concept to the present hydrogen compressor. They are mounted on either side of the engine, on the opposite end from the alternator, and are driven through a magnetic clutch by an eccentric-type crankshaft which imparts the reciprocating motion to the compressor pistons. The compressors are arranged so that their piston reciprocating forces cancel each other. Both compressors will be declutched when operation on supercritical tankage is desired.

Engine Design

Exhaust ports will be retained despite the possibility of greater oil loss, due to their simplicity and mechanical reliability. A positive displacement oil pump operating in high pressure pulses in a throw away lube system is the first choice. A recirculating system will be considered if time permits.

The major remaining design problem in the component design study concerns the oxygen injector. Oxygen flow will be controlled by throttling, probably with a needle valve, slightly upstream of the injector. The flight design oxygen injector will be similar in concept to the present injector with more positive control of poppet movement.

CONTROLS

No effort has been expended on controls during this period. The final report on the controls study will be completed by April 30, 1963.

ELECTRICAL

The alternator and the d-c starter generator have been sized and will be incorporated into the flight design system layout drawing. The starter generator is mounted inside the annulus of the toroidal alternator. The starter generator has an internal rotor and an external stator and the alternator has an external rotor, so that the stationary components of both machines are adjacent. The rotating components share the same engine driveshaft. No gearbox is used, since both are driven at engine speed (4000 rpm). The starter generator furnishes engine starting power (from current supplied by a storage battery), d-c power for the control elements, and excitation current for the alternator.

RELIABILITY

A failure mode study is under way. Reliability effort will be completed within budget limitations by April 30, 1963.

ENGINE AND INJECTOR TESTS

Engine Testing

The engine was assembled and run-in by motoring with a hydraulic motor and by running on cold nitrogen for a total of two hours. A faulty cylinder was used in this assembly because it was the only one available. This cylinder was rejected due to a porous weld joint which allowed water to leak from the cooling jacket to the outside. The leaks were patched with high temperature epoxy and a one minute hot run was made. After the run water was present in the cylinder. Cylinder inspection showed that a crack had opened in the weld between the water cooling jacket and the exhaust manifold ring. It was concluded that water was drawn into the cylinder through the exhaust ports during shut down. The engine could no longer be run with this cylinder using water cooling because water would leak into the cylinder during the up stroke. A rough heat transfer calculation was made to check the feasibility of running the engine using nitrogen cooling. The engine was run using nitrogen cooling. The test was stopped after one minute because of fire around the cylinder head, which started when the epoxy used to seal the water leak cracked loose and allowed combustion products to leak from the cylinder head.

The oxygen injector was disassembled and inspected after this run. The poppet guide, (Haynes LT-1, a sintered composite of chromium and aluminum oxide), was found to be broken; the seat, also LT-1, was pitted; and pieces of the seat were present on the poppet.

The engine was reassembled with a new cylinder; Haynes Stellite #25 poppet, guide, and seat; and a new cam cover plate with an adjustment for the follower hold down spring. The new cylinder was run-in by hydraulic motoring and by cold N_2 operation, as before.

During preliminary run-in a drop in nitrogen flow through the oxygen injector was noticed. The cam follower was found to be badly worn and cocked in the rocker arm. The edges of a new cam follower were ground down to prevent the possibility of corner interference with the rocker arm. The engine was run as an expansion engine again, and flow through the O_2 injector was seen to drop again after a few minutes operation. Another cam follower was ground on the corners only to prevent the possibility of interference while maintaining as large a bearing surface as possible between the guides of the rocker arms. The engine was run on cold gas with this new follower. This time, flow through the oxygen injector remained steady.

Two 4 minute hot runs were made. After the hot runs, the follower was found to be worn. A crowned follower designed to remain fixed with respect to the rocker arm was fabricated.

A hot run of 12 minutes was made with the crown follower. Two data points were taken during this run, with the following results:

rpm	HP out	O_2/H_2	BSPC
3000	1.29	.924	2.44
3500	2.06	.907	2.332

A second hot run of 17 minutes was made with the results as follows:

rpm	HP out	O_2/H_2	BSPC
4000	.58	1.225	2.898

The run was stopped because of a cylinder head failure. The rupture in the cylinder head was attributed to over stress in the thin (approximately .060") section caused by the sealing preload of the head screws. A new ring has been fabricated so that the seal load will be taken near the outside diameter of the head.

Both the crowned cam follower and the cam were badly galled. The corner of the high point of the cam near the injector was worn down. Faulty lubrication is believed to be the cause of the cam and follower failure. This belief is based on the following facts: (1) the follower was badly galled but not pitted, (2) a similar follower shows only minor wear after 25 minutes with MIL-H-5606 lubrication on the injector test stand, (3) the engine test stand lubrication system had been drained and refilled and the cam cover plate which contains the cam lubrication tube was changed. The lubrication pump was operated and oil flow was observed through the hold down spring port. The cam oiler tube was found to be partially plugged so that the oil stream did not reach the cam. It has not been determined whether or not any of the failures of the line contact followers were due to lubrication failure. Line contact failures also occurred on the injector test stand with a high rate of lubricant flow. However, MIL-H-5606 bled off the motoring circuit was used, which is not a good lubricant.

High Hertz stress and pressure velocity for the crowned follower were indicated by calculations. Due to the compound motion of the follower, very high contact pressure will occur once any wear has started. It is planned to continue using the crown follower with a high flow of lubricant, while design studies are conducted on a follower pivoted about a pin parallel to the cam axis.

Injector Bench Tests

The two assembled O_2 injectors have been designated A and B.

Injector A was run for two hours on the injector test stand with a line contact follower and an LT-1 seat and poppet guide. MIL-H-5606 was used as lubricant. Ambient N_2 gas was supplied to the unit at varying pressure and the drive speed was varied. The injector was inspected at the end of the run. The seat was pitted, the guide broken and the follower galled. Injector A was rebuilt with a Haynes Stellite #25 seat and guide and placed on the engine.

The LT-1 guide and seat also failed in injector B during engine running. Injector B was removed from the engine and placed on the injector stand with a Haynes 25 seat and guide. It was run for one-half hour with MIL-H-5606 lubrication at 3500 rpm, using 700 psig ambient nitrogen. The follower galled during this run.

Injector B was then run using a crowned follower for three hours with MIL-H-5606 lubrication, 4000 rpm and 400 psig N_2. The follower showed only mild wear over an elliptical surface approximately 3/16" by 1/16".

The test stand has been modified to use SAE 30 oil for cam lubrication instead of MIL-H-5606.

REGENERATOR

The regenerator has been fitted with a view window and additional thermocouples and has been insulated. It is in the process of being mounted on the engine test stand. A liquid nitrogen line has been installed to the engine test cell.

COMPRESSOR

The compressor test set-up has been checked out and is functioning properly.

A total of 2 hours and 48 minutes of running time has been accumulated on the compressor. The first 45 minutes was used in learning to operate the test system and no data were taken. Data were taken during the 5 tests to follow. Data were not reduced in detail because volumetric efficiency was extremely poor on all tests indicating that development was required. All tests were done with only the first stage functioning. Check out tests used nitrogen gas. Later tests used hydrogen gas cooled by liquid nitrogen.

Runs 1 and 2 used Koppers glass filled teflon compression rings and rider ring. The remaining tests were with "T" rings consisting of a Kel-F expansion "T" ring with two virgin teflon compression rings and a rider ring supplied by C. Lee Cook Co. The Cook representative recommended virgin teflon originally, but the rings received were glass filled teflon. The Cook compression rings were not run because they were not light tight. The "T" rings were light tight and had much superior static compression to the Koppers rings.

After run 3, the first stage cylinder was removed and a soft gray powder from the Cook rider ring was found in the crank case and cylinder and in the clearance between the "T" ring and its groove. The powder was cleaned from the compression ring groove and the compressor was run on hydrogen (run 4). The lowest ring leakage of any test was recorded during this test. During run 5, however, ring leakage again increased. The compression ring was again jammed with powder from the rider ring. Measurement showed that the compression ring was below the piston diameter. Ring width clearance was increased so that gas pressure could get under the ring and hold it out. Further running is postponed while virgin teflon rider rings are being procured.

While waiting for the new rider rings, work was done on the valving. The first stage inlet valve cracking pressure was reduced from 3 psi to 1-3/4 psi by selecting the lightest of 10 available springs. A pressure of 60 psi was required to crack the first stage outlet valve. After opening it stuck open. The teflon filled bronze bushing was grabbing the poppet stem in the area where the bushing screws into a conical seat. Parts are being modified to correct this condition.

A catastrophic failure occurred during compressor run 2. The screw holding the piston to the flex drive assembly loosened, and hit the cylinder causing failure of the flex drive assembly and the external drive linkage in addition to piston damage. The failure occurred at 4000 rpm.

It was also realized that center displacement of the flex pivot under load could have contributed to this failure. This possibility may prevent the running of extremely small clearance volumes as long as a flex pivot is employed. It was also realized that if the center deflection of the pivot is appreciable, then the clearance volume will change with speed and pressure. We are awaiting center deflection vs. load information from Bendix. The above considerations, in addition to down grading the predicted endurance life of the flex pivot (as discussed in last report), makes a more rigid link between the piston and rocker arm appear desirable.

Next effort will be directed towards improvement and documentation of first stage performance, since a single stage unit should be sufficient for engine pressure requirements.